APPENDIX 5-15

WIND AND RAINFALL ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BLACK & VEATCH

TECHNICAL MEMORANDUM

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Work Order No. 3

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Task 5.3.5.7 Wind and Rainfall Analysis

To: Distribution

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1. OBJECTIVE

The overall objectives of the Wave Run-up Model are as follows:

- To determine the amount of freeboard required to prevent over-topping of the reservoir embankment during high wind and rain conditions,
- To determine the effectiveness of internal breakwaters in decreasing wave run-up.

This memorandum summarizes one of the tasks completed in developing the Wave Run-Up model and includes a discussion of wind data analysis and rainfall data analysis.

2. AVAILABLE DATA

Winds at the project site will be a key factor in determining the freeboard requirements because wind velocity and duration will be the driving mechanism for producing waves in the reservoir. Wind direction and speed are needed for stations around the EAA reservoir site. The South Florida Water Management District (District) online database contains only daily average values for wind speed and other meteorological data. Furthermore, there were very few stations in the District's database that had a combination of both direction and speed measurements. Since the Wave Run-Up model needs a finer resolution than daily average values for wind speed and direction and because few District stations had appropriate wind data, other sources were used.

The National Climatic Data Center (NCDC) has weather stations all across the United States. Stations designated as "first order" are those where data are recorded by trained personnel and whose meteorological instruments are constantly maintained. These weather stations are known to have the most robust and reliable meteorological data. Four first order stations around the proposed EAA reservoir were selected based on proximity to the EAA reservoir site and parameters measured at the sites. Hourly digital wind direction and speed, along with other meteorological parameters were obtained for the stations listed below:

- Orlando International Airport: WBAN 12815FL
- Fort Meyers Page Field: WBAN 12835FL
- West Palm Beach: WBAN 12844FL

- Avon Park Gun Range: WBAN 12804FL

Additional data specific to hurricanes was obtained from the NOAA Tropical Prediction Center. These additional data are contained in reports for individual hurricanes and in reports summarizing the effects of hurricanes.

In conjunction with the Tropical Prediction Center, the NOAA Coastal Services Center provides an online database for hurricanes and storms. A search was performed to identify all the hurricanes which passed within 100 nautical miles of South Bay, Florida, a city located close to the proposed EAA reservoir location. The search was performed for those hurricanes which occurred between 1950 and 2003, since access to reports and robust meteorological data preceding 1950 is limited. Eleven hurricanes were identified. When the three hurricanes of 2004 are included, a total of 14 hurricanes have come within 100 nautical miles of South Bay, Florida during the past 54 years. Figure 1 presents the hurricane tracks of the 11 storms and their relative intensities. Figure 2 presents the tracks of the three hurricanes of 2004 (Bossak, 2004).

Individual cyclone reports were obtained for each of the 14 hurricanes. The cyclone reports present information on the origin and history of the storm, the storm track, winds, barametric pressure, and rainfall amounts. The reports include tabulations from numerous stations showing conditions along the hurricane tracks. Data from the following hurricanes were included in the analysis:

- Charley, 2004
- Jeanne, 2004
- Frances, 2004
- Irene, 2004
- Erin, 1995
- Andrew, 1992
- Floyd, 1987
- David, 1979
- Inez, 1966
- Betsy, 1965
- Cleo, 1964
- Isbell, 1964
- Donna, 1960
- King, 1950

Rainfall data were obtained from the District. They are the same data used for previous modeling conducted using the SFWMM (2 x 2 model). Additional rainfall data obtained from the tropical cyclone reports were also used in the analysis.

3. METHODOLOGY

Wind data collected at the four stations listed on the previous page were analyzed to determine frequency distributions of speed and direction. The wind data were analyzed to produce the following summaries for each of the four stations:

- histograms of wind speed at each station
- histograms of wind direction at each station
- graphs of percent exceedance

The wind data only rarely showed speeds of hurricane force winds, which raised some concerns that the routine measurements accurately recorded the hurricane events. This was confirmed by the tropical cyclone report for Charley (Pasch et al. 2004):

"As usual, there were no official surface anemometer measurements of wind speeds even approaching the intensity estimate near the landfall location. …it is highly likely that much stronger winds would have been observed at the site [Punta Gorda, Florida], had the wind instrument not failed. Instrument failures remain a chronic problem in landfalling hurricanes."

Therefore, a comparison was made of the wind speeds recorded during routine wind measurements and data recorded for the tropical cyclone reports. The tropical cyclone reports were also used to track the decrease in wind speed as hurricanes passed over land.

Information for the more recent storms from the NOAA tropical cyclone reports included estimates of hurricane location and maximum sustained wind speed. For earlier hurricanes and location data were sometimes provided which was sufficient for our analysis. The available data were extracted from these reports and plotted using ArcGIS. A relationship was then determined by plotting estimated maximum sustained wind speed versus the distance traveled overland from landfall.

Rainfall data were analyzed to determine the following:

- annual and monthly averages
- peak 1, 2, and 3 day totals
- the correlation between rainfall and category of hurricane
- average rainfall associated with each category of hurricane.

The results of the wind and rainfall analyses are presented in the next section.

4. RESULTS

4.1 Routine Wind Measurements

Basic wind characteristics were calculated for each of the four weather stations. Table 1 presents the results of this analysis and includes: the period of record, total number of observations, median wind speed, 99 percentile wind speed, and maximum wind speed. Figures 3, 4, 5, and 6 present the wind speed histograms for Avon Park, Fort Meyers, Orlando, and West Palm Beach, respectively. Figures 7, 8, 9, and 10 show the wind speed exceedance percentages for each station.

This information was used to define the prevailing wind speeds at the proposed EAA reservoir under most conditions excluding hurricanes. The period of record for these stations is about 50 years and included a wide range of meteorological conditions. However, as discussed previously, anemometers at many surface stations stop functioning during hurricanes. The next section presents additional wind data specific to hurricanes that have affected the region in the past 50 years.

Figures 11, 12, 13, and 14 illustrate the wind direction histograms for Avon Park, Fort Meyers, Orlando, and West Palm Beach, respectively. For the West Palm Beach station the predominant wind direction is east while for the other three stations, the predominant wind direction is north.

Wind speed and direction are important factors in determining wave heights. However, for this analysis we have assumed that the design wind speed could come from any direction.

4.2 Hurricane Winds

The Saffir-Simpson Scale is used to rate hurricanes based on its wind speed at the time of classification. The scale is used to indicate potential damage that the hurricane can produce. The categories are as follows:

- category 1, winds 74-95 mph (64-82 knots)
- category 2, winds 96-110 mph (83-95 knots)
- category 3, winds 111-130 mph (96-113 knots)
- category 4, winds 131-155 mph (114-135 knots)
- category 5, winds greater than 155 mph (> 136 knots)

Hurricanes classified as category 3, 4, or 5 are considered to be major hurricanes.

Of the 14 hurricanes which passed within 100 nautical miles of the EAA Reservoir A-1 site, two were category 4 (Charley 2004 and Andrew 1992); one was category 3 (Jeanne 2004); five were category 2 (Frances 2004, Cleo 1964, Betsy 1965, Donna 1960, and King 1950); and six were category 1 (Irene 1999, Erin 1995, Floyd 1987, David 1979, Inez 1966, and Isbell 1964). This list is based on the wind speed of the hurricane as it passed over Florida, not on the highest wind speed recorded during its lifetime. For those hurricanes which didn't make landfall (list), their category is based on the highest winds recorded on the mainland. Of the fourteen hurricanes passing within 100 nautical miles of the project site since 1950, three were major hurricanes.

Using information presented in the tropical cyclone reports, a relationship was developed between hurricane maximum sustained wind speed and distance inland from landfall. Frictional forces of land along with the removal of the warm ocean waters feeding energy to hurricanes typically produce dramatic changes in hurricane strength. Figure 15 shows the reduction in wind speed as a function of distance from landfall for eight hurricanes. This figure indicates that hurricanes can lose a significant percentage of their intensity and wind speed within the first 50 miles from landfall. This relationship was of interest because the proposed EAA reservoir is located approximately 40 miles inland.

Table 2 shows the percentage reduction of hurricane wind speed 40 miles inland from landfall for eight of Florida's hurricanes occurring in the past 54 years. At a distance of 40 miles inland, a decrease in wind speed of approximately 15 percent was typical for hurricanes passing through this region.

4.3 Rainfall Analysis

Rainfall data was obtained from the District for the period from January 1, 1965 through December 31, 2000. This data set comprises daily rainfall totals for the project site and is the same data set used in the SFWMM (2 x 2 model). Table 3 presents the maximum, minimum and average rainfall amounts on a monthly and annual basis. The peak one-day total rainfall during this period was 6.44 inches on January 16, 1991. The peak two-day total rainfall during this period was 9.12 inches and occurred on November 4 and 5, 1998.

Rainfall data was also obtained from the tropical cyclone reports. These data are summarized in Table 4. The rainfall amounts listed are the highest values recorded at any location in Florida and include rainfall throughout the hurricane. Therefore, the data shown do not reflect actual rainfall at the project site but rather are an indication of the amount of rainfall that could occur as a result of a hurricane.

Of the fourteen hurricanes investigated, Hurricane Erin produced the most rain with a storm total of 20 inches. There is no direct correlation between category of hurricane and rainfall amount. Total rainfall is related more to the speed that the hurricane travels across land than the wind speed. The highest rain producing hurricanes were for category 1 and 2 hurricanes. The average rainfall for category 1 and 2 hurricanes is 11.7 inches, while the average for major hurricanes is 7.2 inches.

5. SUMMARY

The results of the wind data analysis and rainfall data analysis are presented in this memorandum. Hourly digital wind data along with other meteorological parameters were obtained for Orlando, Fort Meyers, West Palm Beach and the Avon Park Gun Range. Rainfall data were obtained from the District and from the tropical cyclone reports for 14 hurricanes.

Basic wind characteristics were calculated for each of the four weather stations. Analysis of the wind data defined what the prevailing wind speeds at the proposed EAA reservoir are likely to be under most conditions excluding hurricanes. Although some hurricane winds are likely to be included in these wind records, anemometers at many surface stations stop functioning during hurricanes. Wind data for hurricanes was derived from the tropical cyclone reports.

Since 1950, 14 hurricanes have passed through an area within 100 nautical miles of the EAA Reservoir A-1 site. Of these hurricanes, two were category 4, one was category 3, five were category 2, and six were category 1. Three of the fourteen hurricanes were major hurricanes. A relationship was developed between hurricane maximum sustained wind speed and distance inland from landfall. For a distance of 40 miles inland, it appears that a decrease in wind speed of approximately 15 percent was typical.

Rainfall data were analyzed to determine annual and monthly averages, peak one, two, and three day totals, and the rainfall associated with hurricanes. Of the fourteen hurricanes investigated, Hurricane Erin produced the most rain with a storm total of 20 inches. Although there is no direct correlation between category of hurricane and rainfall amount, the highest rain producing hurricanes were classified as category 1 or 2. The average rainfall for category 1 and 2 hurricanes was calculated to be 11.7 inches, while the average for major hurricanes was 7.2 inches.

6. RECOMMENDATIONS

The results of the wind and rainfall analyses will be used in part to determine the weather conditions to be simulated with the Wave run-Up model. Weather conditions will include three (3) different combinations of winds and rainfall amounts. Recommended weather conditions to be modeled were identified in Work Order 3 Technical Memorandum #1 submitted to the District on December 29, 2004.

The three conditions were defined as follows:

- The first condition will represent a category one hurricane with normal rainfall associated with a hurricane of that magnitude
- The second condition will represent a hurricane event in combination with the Probable Maximum Precipitation (PMP).
- The third condition will represent a hurricane with very strong winds (category 3 or 4) and rainfall normally associated with that type of hurricane.

A category 1 hurricane can have winds ranging from 74 to 95 mph. The information presented in Table 4 indicated that the highest rainfall totals recorded for category 1 hurricanes ranged from 5.2 to 20 inches with an average of 12 inches. It should be remembered that this average is not the actual average rainfall for all category 1 hurricanes, it is simply the average of the areas that received the most rainfall for each hurricane. The recommended wind and rainfall amounts for the first condition are wind speed of 85 mph with a rainfall of 12 inches.

The second condition addresses the PMP. The PMP will be calculated during a task included in Work Order 5 and will not be completed before the Wave Run-Up model runs are made. However, an initial estimate of the PMP will be made and used in the modeling. Work Order 5 includes a task to make refinements to the wave run-up calculations. When the final PMP value is defined, the wave run-up model will be rerun to determine the freeboard requirements for this condition. The recommended wind speed for the second condition is 80 mph in conjunction with the PMP.

A category 4 hurricane can have winds ranging from 131 to 155 mph. The third design condition includes a category 4 hurricane that makes landfall on the Florida peninsula and travels inland toward the reservoir site. If the winds at the coastline were 155 mph and decreased by 15 percent as the hurricane moved inland, the winds at the reservoir site would be 132 mph. The information presented in Table 4 indicated that the highest rainfall totals recorded for major hurricanes ranged from 5.2 to 9.1 inches with an average of 7.2 inches. The recommended wind and rainfall amounts for the third condition are wind speed of 132 mph with a rainfall of 7 inches.

7. REFERENCES

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U.S. Department of Commerce. Weather Bureau. Hurricane Isbell; October 12-16, 1964; Preliminary Report with Advisories and Bulletins Issued. Washington: 1964

U.S. Department of Commerce. Weather Bureau. Hurricane Cleo; August 20 – September 4, 1964, Preliminary Report with Advisories and Bulletins Issued. Washington: 1964

U.S. Department of Commerce. Weather Bureau. Hurricane Donna; September 2 – 12, 1960, Preliminary Report with Advisories and Bulletins Issued. Washington: 1960

TABLES

Table 1 Basic Wind Data

Location	Period of Record Analyzed	Number of Observations	Median Wind Speed (knots)	99% Wind Speed (knots)	Maximum Wind Speed (knots)
Avon Park, FL	1965-1993	104,168	4	16	41
Fort Meyers, FL	1948-2004	338,028	7	20	97
Orlando, FL	1952-2004	442,585	7	21	61
West Palm Beach, FL	1948-1991	297,766	9	23	120

Table 2 Wind Intensity Versus Distance Inland

Event	Approximate Location of Landfall	Saffir/Simpson Category at Landfall	% Reduction in Wind Speed 40 Miles Inland
Charley	Punta Gorda, FL	4	16.0
Jeanne	Stuart, FL	3	14.3
Ivan	Mobile, AL	3	16.2
Frances	Stuart, FL	2	13.3
Donna	Fort Meyers, FL	2	10.8
Erin	Vero Beach, FL	1	14.7

Table 3 Rainfall Data for EAA Reservoir A-1 Site

Month	Maximum	Minimum	Average
January	10.17	0.15	2.13
February	8.24	0.05	1.95
March	10.59	0.11	2.56
April	9.83	0.00	2.42
May	10.92	1.04	4.80
June	18.24	1.72	8.65
July	12.03	2.13	6.92
August	16.15	4.21	7.07
September	11.99	2.21	6.60
October	11.10	0.31	3.76
November	9.45	0.12	2.30
December	9.38	0.13	1.73
Annual	65.34	37.52	50.91
Notes 1. Rainfall Amounts in Inches 2. Period of Record: January 1, 1965 through December 31, 2000			

Table 4 Rainfall Data for Hurricanes

Hurricane	Category	Location	Date	Rainfall (inches)
Erin	1	Defuniak Springs	8/2/1995	20.0
Frances	2	High Springs	9/5/2004	15.8
Irene	1	Homestad AF	10/15/1999	14.6
Donna	2	Merathon	9/10/1960	12.1
Jeanne	3	Palm Beach	9/26/2004	9.1
David	1	Ft. Drum	9/3/1979	8.1
Andrew	4	Broward County	8/24/1992	7.8
Cleo	2	Miami	8/27/1964	6.8
Floyd	1	Naples	10/12/1987	5.2
Charley	4	Kissimmee	8/13/2004	5.2
Note: Rainfall Data were not reported for hurricanes Inez, Betsy, Isbell, and King				

FIGURES

Figure 1 Historical Tropical Cyclone Tracks

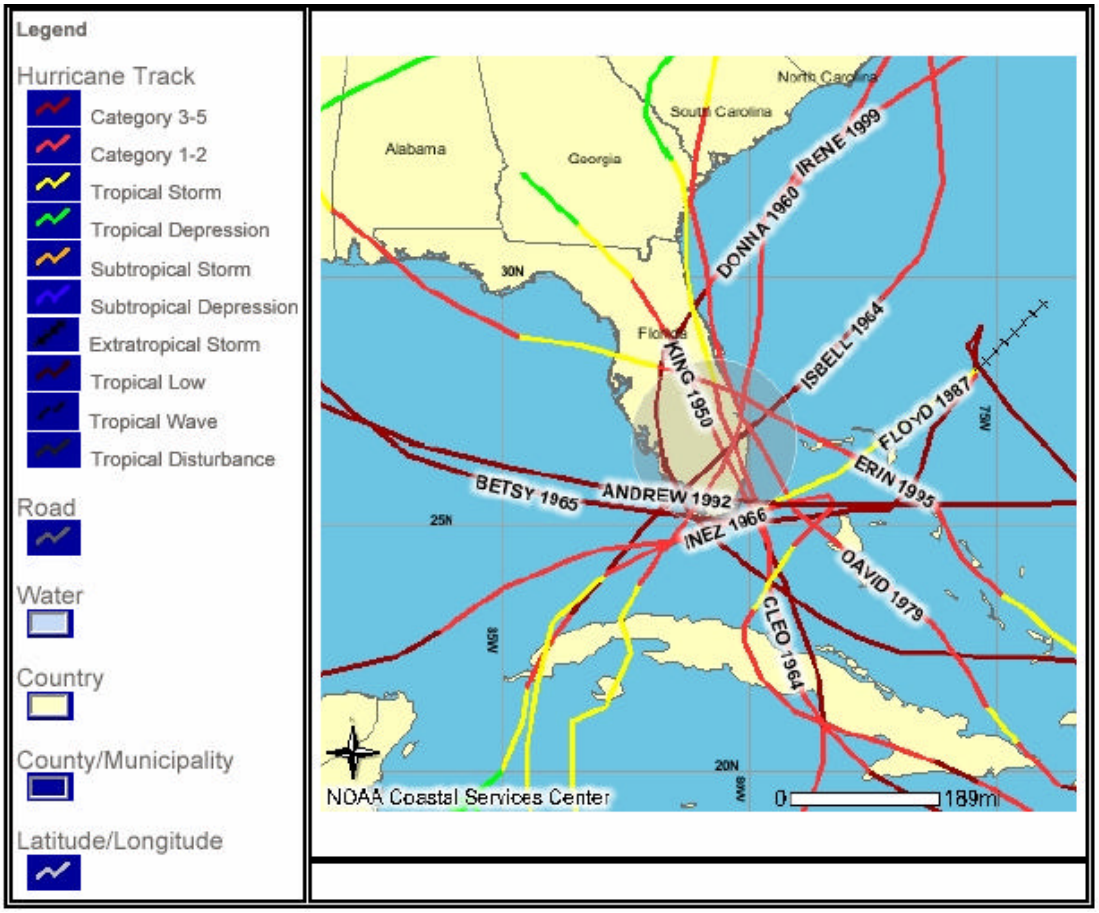


Figure 2 Tracklines for 2004 Hurricanes

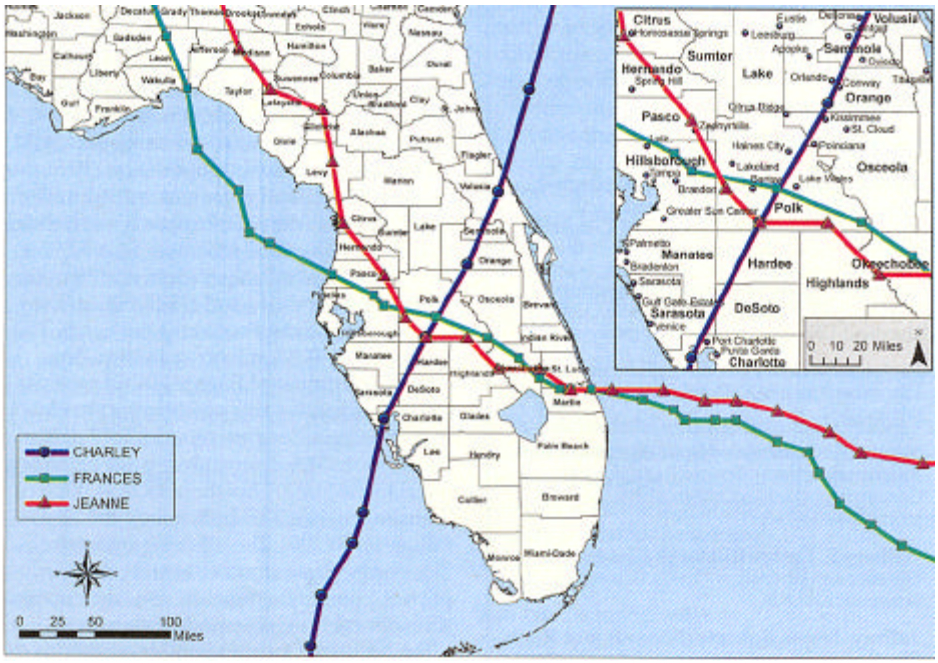


Figure 3 Avon Gun Range Wind Speed Histogram

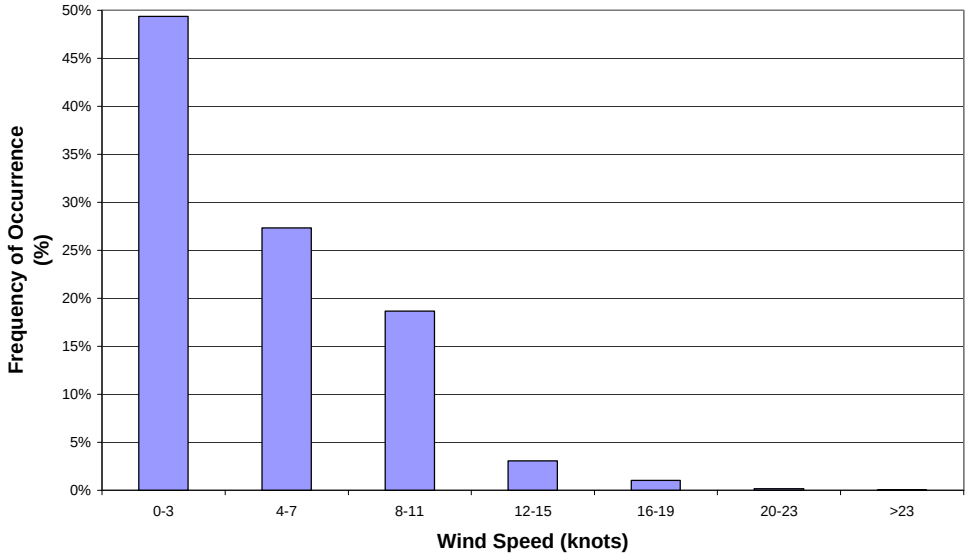


Figure 4 Fort Meyers Wind Speed Histogram

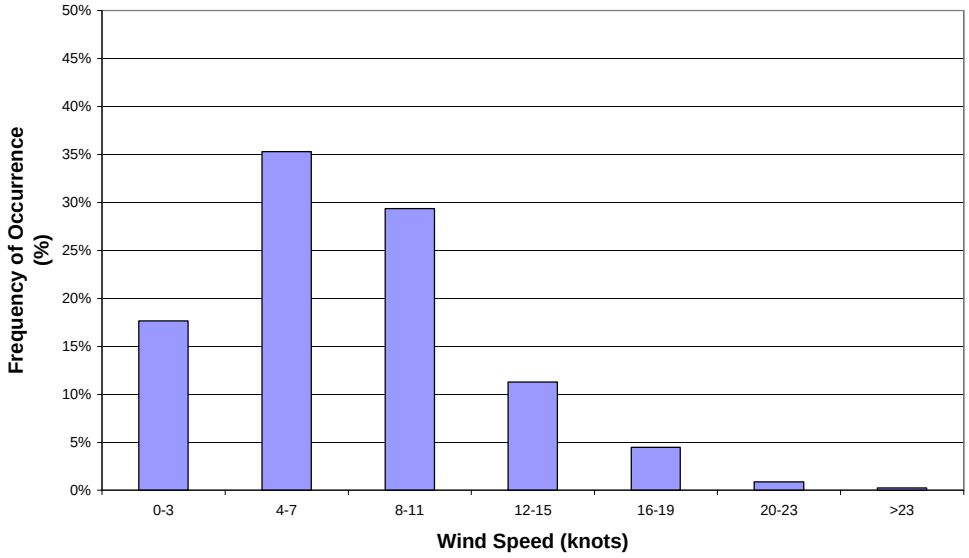


Figure 5 Orlando Wind Speed Histogram

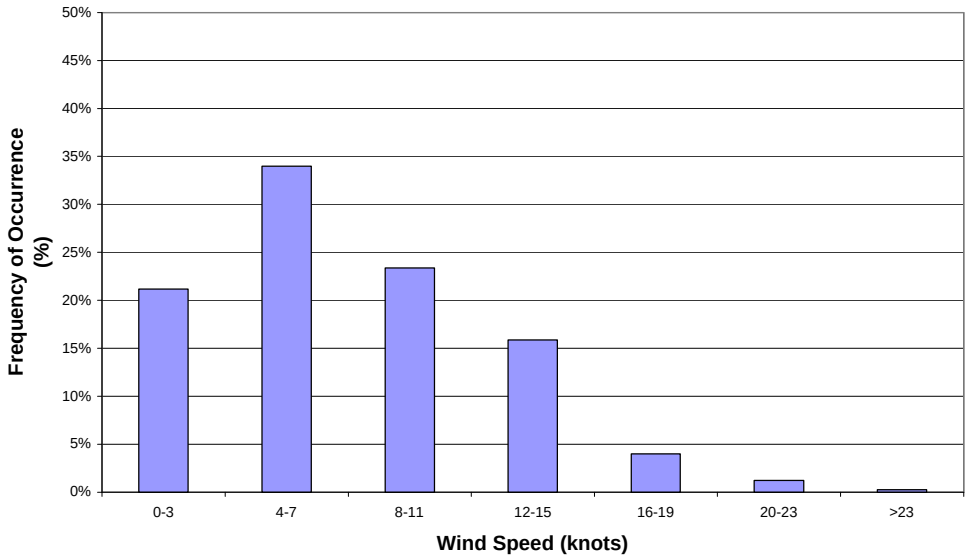


Figure 6 West Palm Beach Wind Speed Histogram

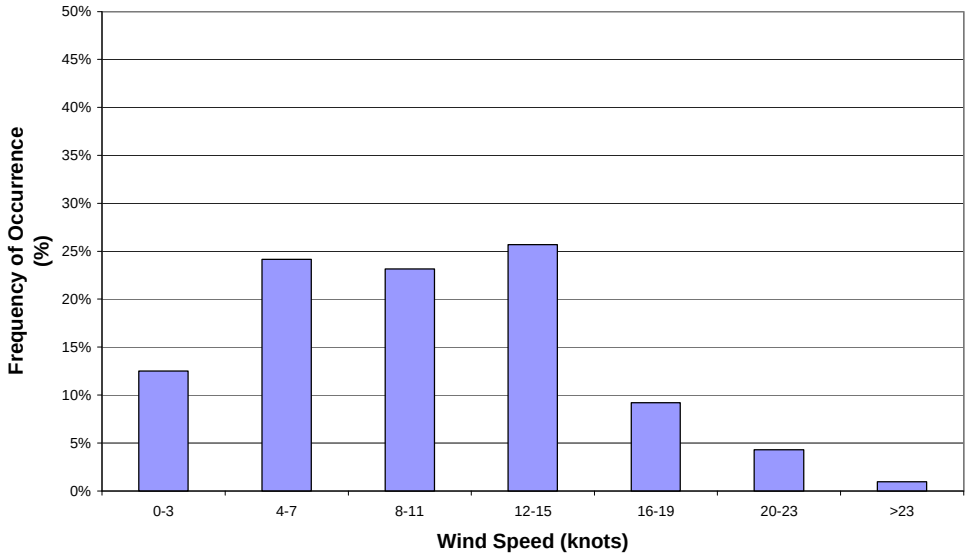


Figure 7 Avon Gun Range Wind Speed Exceedance Probability

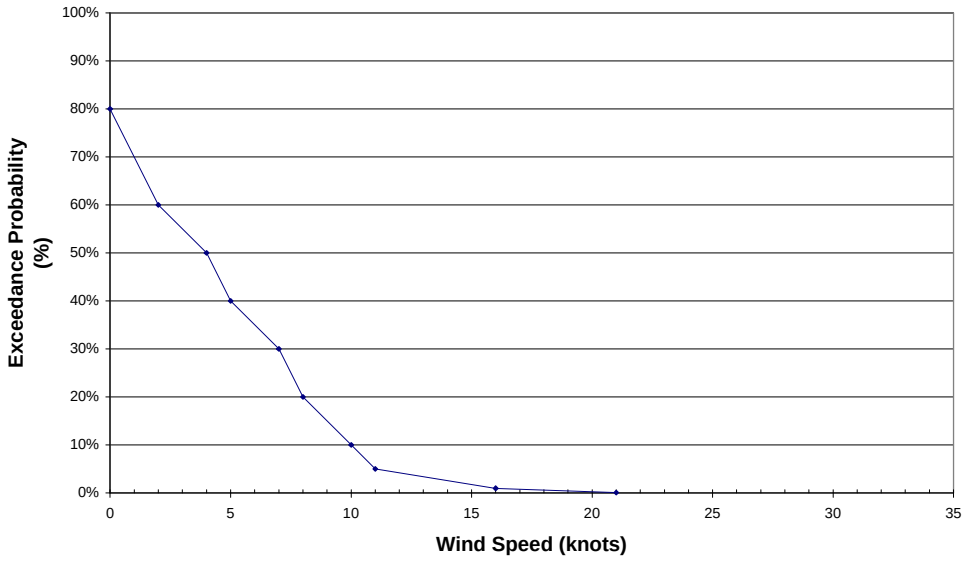


Figure 8 Fort Meyers Wind Speed Exceedance Probability

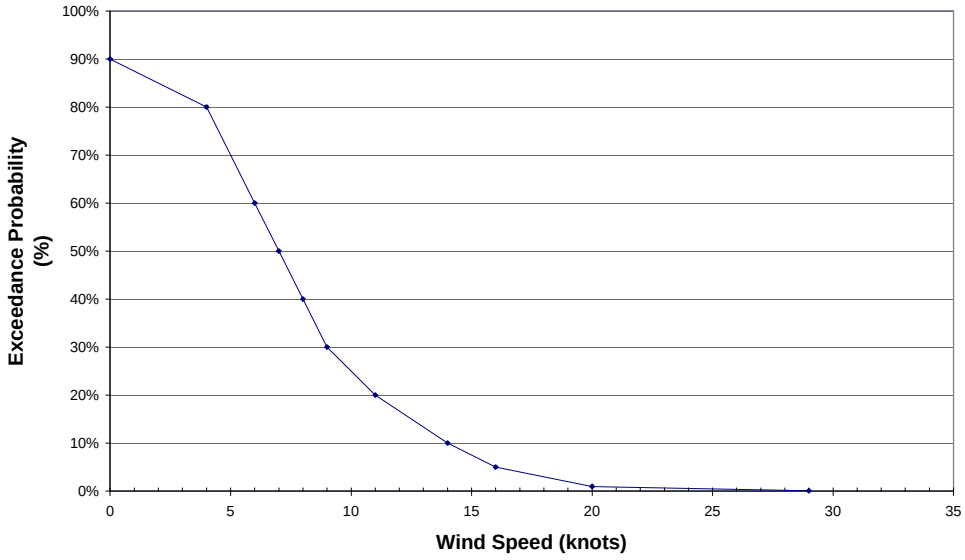


Figure 9 Orlando Wind Speed Exceedance Probability

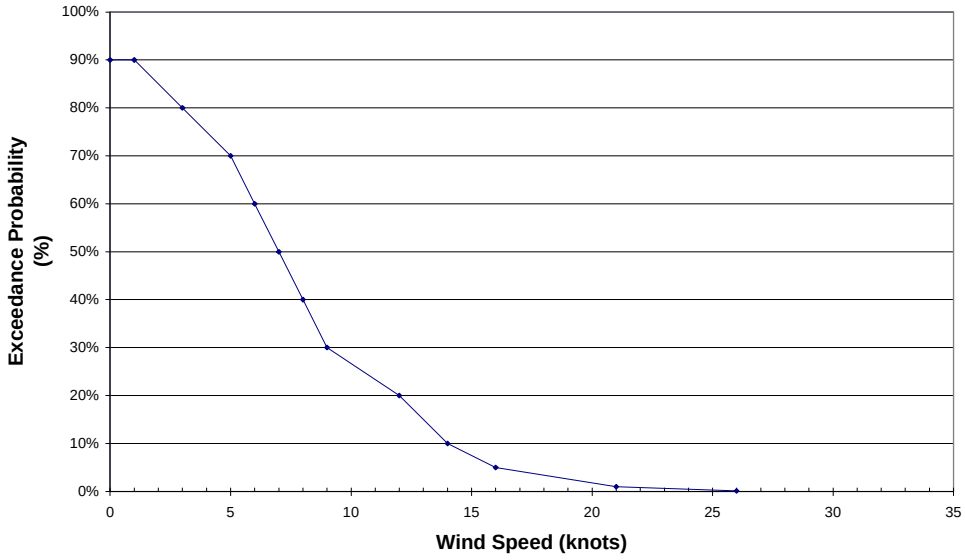


Figure 10 West Palm Beach Wind Speed Exceedance Probability

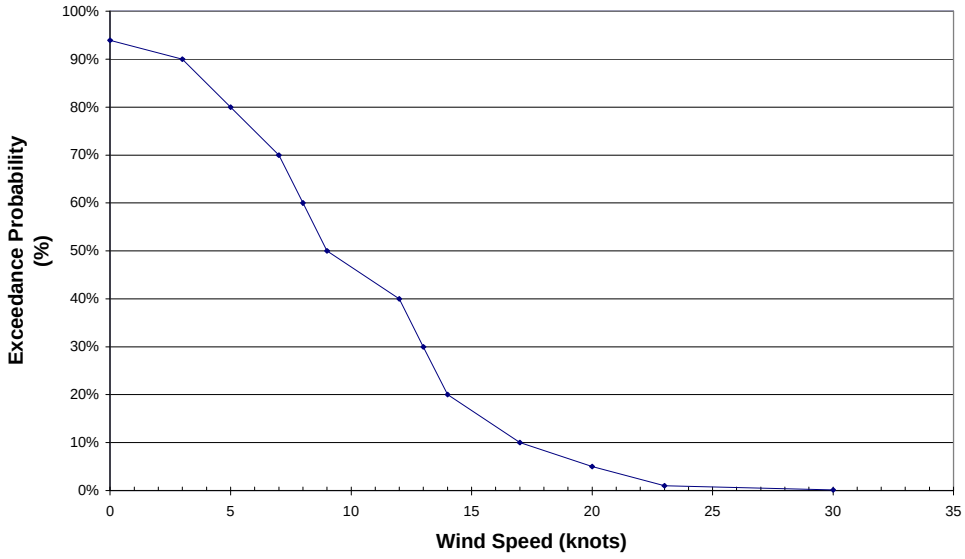


Figure 11 Avon Gun Range Wind Direction Histogram

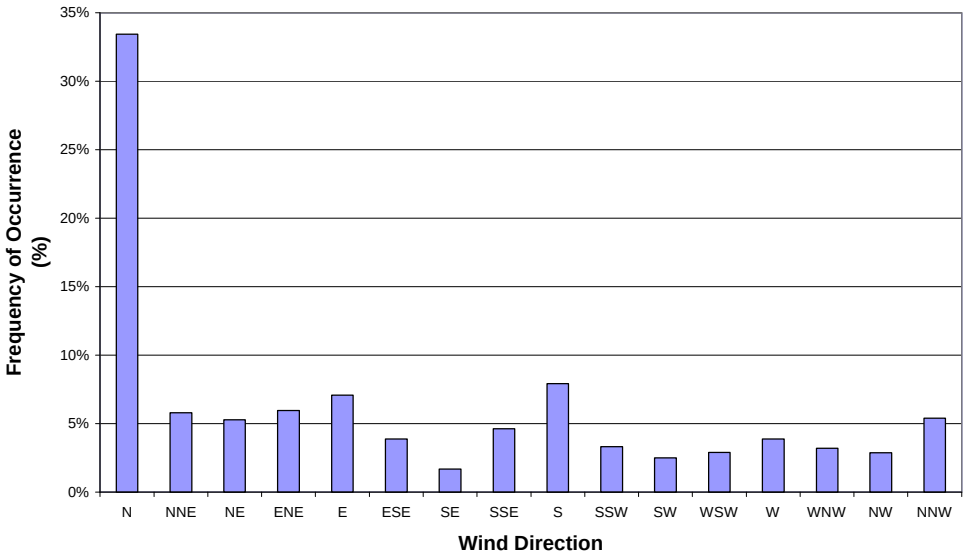


Figure 12 Fort Meyers Wind Direction Histogram

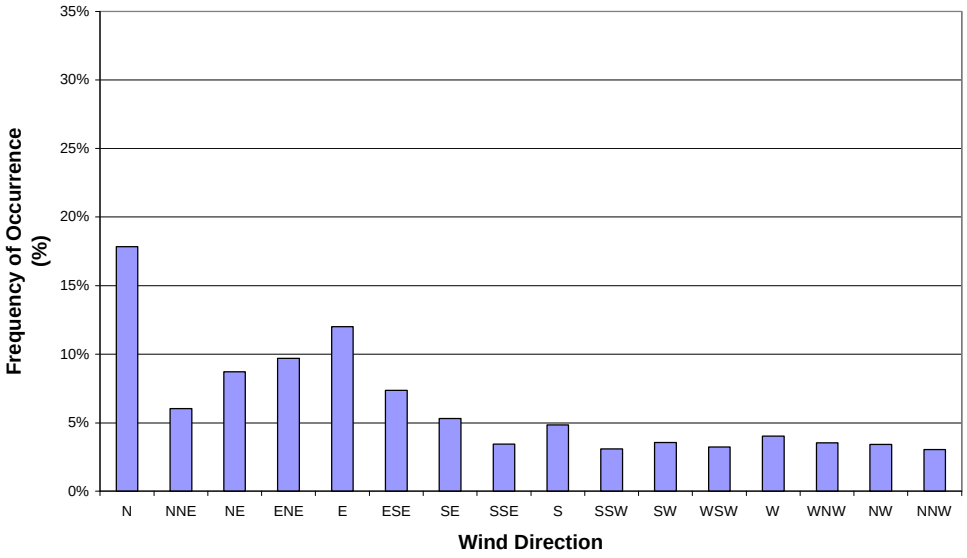


Figure 13 Orlando Wind Direction Histogram

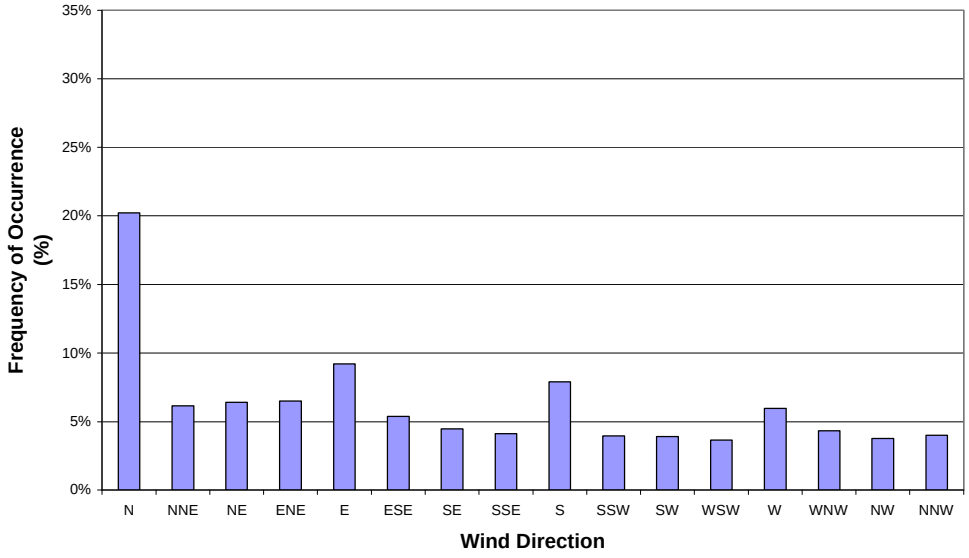


Figure 14 West Palm Beach Wind Direction Histogram

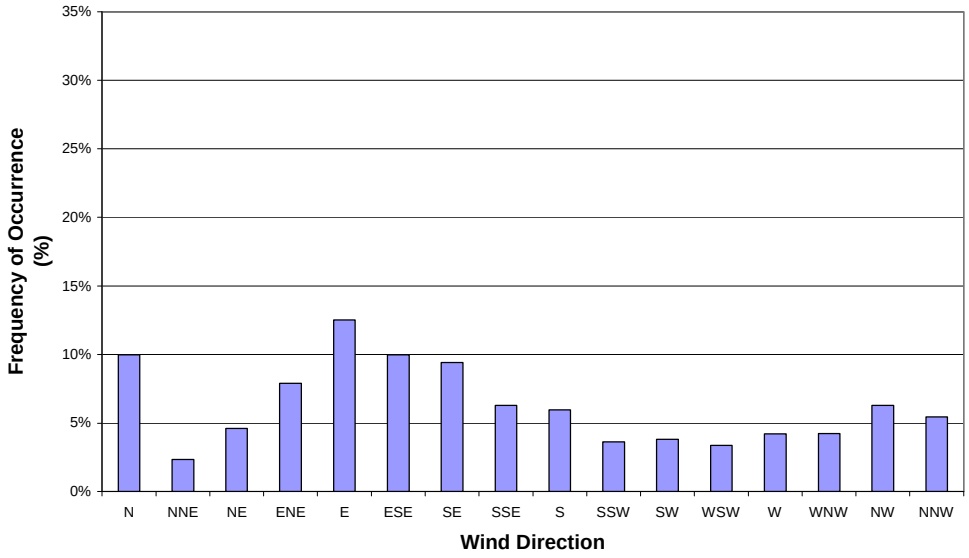
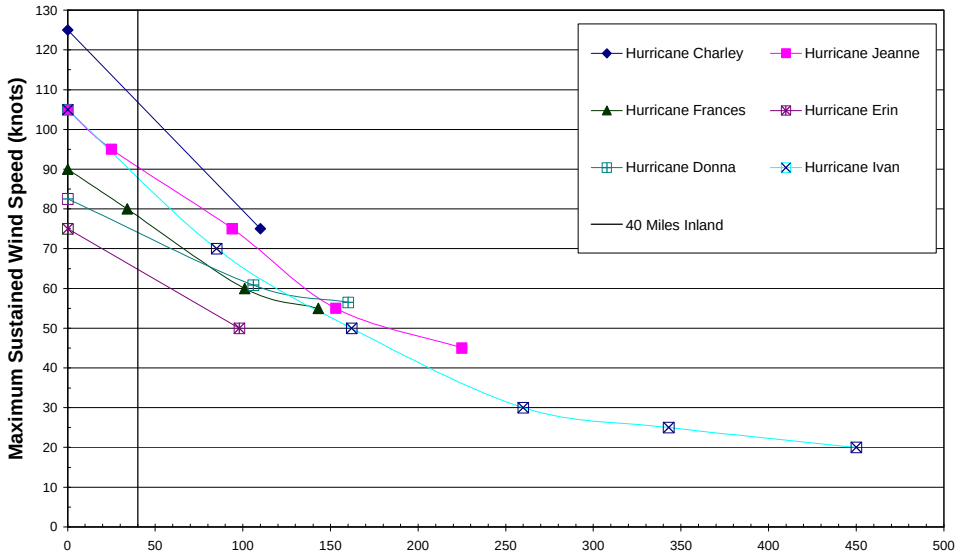


Figure 15 Reduction in Wind Speed as a Function of Distance from Landfall



Note: Hurricane Ivan was added since good wind speed/storm track information was known and because it was recent.